



## Corn consumption in native populations of Mendoza (central-western Argentina) and its relation to environmental conditions

*Consumo de maíz por poblaciones nativas de Mendoza (centro-oeste argentino)  
y su relación con las condiciones ambientales*

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### ABSTRACT

In this article we analyze data on hydroxyapatite  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  from dated human bones, in order to evaluate the variability of corn eating, the possible incidence of the Little Ice Age (LIA) environmental changes on the regional production and consumption of this cereal by the native populations of central-western Argentina. We also evaluate whether or not the average curves are representative of sub-regional situations. Our results show that: a) the regional  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  curves are only partially representative for the situations recorded in San Juan and Mendoza. b) When considering the diverse environments of Mendoza, the provincial average curves and the sub-regional ones show significant differences. c) There are no signs of a drastic decrease in maize consumption during the Inca period. d) The decline in maize consumption appears in only one sub-region of Mendoza province during ca. 1777-1808 AD and no environmental incidence was detected.

### RESUMEN

*En este artículo se analiza la información isotópica de  $\delta\text{C}^{13}$  (hidroxiapatita) y  $\delta\text{N}^{15}$  de huesos humanos, a fin de evaluar la variabilidad del consumo de maíz, la posible incidencia de los cambios ambientales de la Pequeña Edad del Hielo sobre la producción regional y el consumo de este cereal, y si las curvas promedio son representativas de las situaciones zonales. Nuestros resultados indican que: a) las curvas  $\delta\text{C}^{13}$  y  $\delta\text{N}^{15}$  son sólo parcialmente representativas de las situaciones regionales registradas en Mendoza y San Juan. b) Cuando se consideran los distintos ambientes de Mendoza, la curva promedio provincial y las subregionales muestran diferencias significativas. c) No hay evidencias de un descenso drástico del consumo de maíz durante el período incaico. d) La*

*disminución del consumo de maíz aparece en una sola subregión de Mendoza, durante ca. 1777-1808 d.C. y no se detectaron incidencias ambientales en la misma.*

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**Key words:** Central-western Argentina, diet, environmental change, Inca, stable isotopes, Little Ice Age, maize

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**Palabras clave:** Centro-oeste argentino, dieta, cambio ambiental, incas, isótopos estables, Pequeña Edad de Hielo, maíz

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## INTRODUCTION

Central-northern Mendoza is the southern boundary of the dispersion of pre-hispanic cultivation of maize in the arid Argentinean west (Gil 1997-1998; Gil et al., 2010, 2014). The presence of corn in the native food was already highlighted in the mid-twentieth century by Canals Frau (1946), at a time when regional archaeological and documentary research was in its early stage and the available information was very scarce. Subsequent works allowed for the broadening of this vision and registering the presence of other plant resources in the local diet (e.g., Bárcena et al., 1985, Durán & García, 1989; García, 1992). Maize has been registered only in two sub-regions of Mendoza. In the Huentota Valley maize remains appeared at the Memorial de la Bandera site (Chiavazza, 2015), associated with a date of  $1230 \pm 60$  BP (LP 2644). In the pre-Andean valleys and the neighboring eastern precordilleran sector, the findings were more numerous. In Cueva del Toro, corn appeared in contexts corresponding to the period 600-1530 AD (García, 1988); in Los Conitos 1 and 2 (Cortegoso, 2006) it was part of contexts dated between  $1050 \pm 40$  (Uru 0250) and  $1560 \pm 50$  BP (Uru 0251); in San Ignacio (Gasco et al., 2011) appeared at a level dated to  $1310 \pm 40$  BP (Uru 0301), in El Jagüelito Cave (García, 1992) with dates of  $1050 \pm 80$  (I 14291) and  $980 \pm 50$  BP

(LP 309), and in Agua de la Cueva at a level dated  $1450 \pm 40$  BP (Beta 26248-1) and other of an age between 1450 and 1530 AD (Durán & García, 1989). The oldest record in this area comes from the site Agua de la Tinaja (Bárcena et al., 1985) and could be associated with a date of  $2340 \pm 80$  BP (Beta 8580).

Succeeding isotopic analyzes allowed us to consider another type of evidence (human bones) and infer the proportion of corn in the indigenous diet of Mendoza and San Juan (e.g. Gil et al. 2009, 2010). A recent regional trend of hydroxyapatite  $\delta^{13}\text{C}$  ( $\delta^{13}\text{Cap}$ ) points out that the consumption of maize by native groups in central-western Argentina (provinces of San Juan and Mendoza) would have decreased since the Inca times due to climatic changes recorded between 1370 and 1750 AD (Gil et al. 2014). This hypothesis comprises a number of components open to discussion, including the representativeness of the proposed regional curve, the decline in indigenous maize consumption since the Inca period, the incidence of the Little Ice Age (LIA) in a drastic fall in maize production, and the role of maize in the indigenous diet change during Spanish conquest. An alternative reading of the same database offers a different vision for the province of Mendoza and for the sub-regions that contributed with samples for the isotopic studies.

## MATERIALS AND METHODS

The analyzed data were extracted from Gil et al. (2014). The sub-regional study of Mendoza comprised 28 samples with  $\delta^{13}\text{C}_{\text{ap}}$  data (Table 1). To compare the provincial trends with the average curves we considered 73 samples from Mendoza and 44 from San Juan containing  $\delta^{13}\text{C}_{\text{ap}}$  or  $\delta^{15}\text{N}$  data. A sample obtained from the Inca mummy of Cerro Aconcagua was not included because the victim would not have belong to local populations (Bray et al., 2005).

Although not all  $\text{C}_4$  contribution to the diet comes from the consumption of corn (Cadwallader et al., 2012; Llano & Ugan, 2014), this is the most likely source, not only because the information on the apatite reflects carbohydrate sources (Ambrose & Norr, 1993), but also due to the scant presence in the regional archaeological record of other  $\text{C}_4$  o CAM vegetables, such as amaranth, reeds, or cacti. Nevertheless, this point is discussed below. Gil et al. (2014) consider that  $\delta^{13}\text{C}_{\text{ap}}$  values close to  $-8\text{‰}$  reflect approximately 50% of the diet. Based on this calculation and the dispersion of values recorded at the regional level, we have considered a scale of corn consumption that regards the categories very high (greater than  $-7\text{‰}$ ), high ( $-7.1$  to  $-9\text{‰}$ ), medium ( $-9.1$  to  $-11\text{‰}$ ), low ( $-11.1\text{‰}$  to  $-13\text{‰}$ ), and very low (less than  $-13\text{‰}$ ).

As many of the analyzed samples have no contextual data, it is not possible to determine cultural differences having an influence on the maize consumption of particular individuals. Therefore, it is assumed that all samples have the same level of confidence and are normal (instead of potential outliers).

Five geographical zones were differentiated for the samples (Figure 1): a) the lacunar area of the Northeast; b) the pre-Andean valleys of the Northwest, including Uspallata Valley and nearby sites; c) the central valley of Huentota (where the city of Mendoza is located); d) Barrancas and nearby sites, in the badlands near the middle stretch of the Mendoza River; e) the Jaurúa Valley, from where come the samples of Cápiz and San Carlos. Provincial and sub-regional temporal trends of the isotopic information for  $\delta^{15}\text{N}$  and  $\delta^{13}\text{C}_{\text{ap}}$  were examined by plotting Loess curves generated with the PAST3 software, using a 0.6 smoothing parameter (Figures 2-5). We examined the  $\delta^{13}\text{C}_{\text{ap}}$  and  $\delta^{15}\text{N}$  curves of San Juan to compare them with those of Mendoza and test the representativeness of the regional average curves.

## Environmental framework

The center-north of Mendoza presents, from west to east, three large morpho-structural units: the Cordillera, Piedmont, and the Plain. Within these units, there are environmental differences that give rise to multiple sub-regions. Among them, we consider in this work the inter-mountain valleys of the Northwest, the Huentota and Jaurúa valleys, the north-eastern lagoon zone, and the Barrancas badlands. In all these areas agricultural activity was always possible through irrigation.

The pre-Andean valleys of Uspallata and Potrerillos, located between the mountain range and the foothills, at 1500-2000 m a.s.l., are areas of accumulation of trawling material, with deep soils suitable for cultivation (Espízua, 1993a). This zone has an arid-semi-arid Mediter-

**Table 1.** Chronological and isotopic data of the samples considered for the sub-regions of Mendoza (from Gil *et al.*, 2014)

*Tabla 1. Datos cronológicos e isotópicos de las muestras consideradas para las subregiones de Mendoza (tomados de Gil et al., 2014)*

Zone	Site	Lab.	Years $^{14}\text{C}$ BP	Media $2\delta$	$\delta^{13}\text{C}_{\text{ap}}$
Northeast Lagoons	El Rincón	AA-101148	$840 \pm 44$	1198	-13.1
	Laguna del Rosario	AA-90281	$1338 \pm 44$	682	-14.1
	Laguna del Rosario	AA-101147	$1063 \pm 47$	974	-14.1
	Alto La Echuna	AA-101149	$1036 \pm 43$	998	-14.3
Northwest pre-Andean Valleys	Uspallata	AA-66558	$1922 \pm 52$	82	-9.9
	Finca Alí	AA-101143	$1862 \pm 35$	153	-7-4
	Barrio Ramos	AA-98708	$583 \pm 43$	1351	-9.4
	Barrio Panella	AA-101144	$1902 \pm 40$	104	-7.1
	Potrero Las Colonias	AA-666564	$568 \pm 38$	1353	-4.2
	Túmulo II Uspallata	AA-66561	$1269 \pm 35$	730	-7.5
	Túmulo II Uspallata	AA-66565	$1178 \pm 41$	844	-6.5
	Túmulo I Uspallata	AA-66568	$977 \pm 35$	1084	-11
	Túmulo III Uspallata	AA-66566	$671 \pm 40$	1317	-3.4
	Agua de la Cueva	UGA-8660	$2480 \pm 50$	-620	-5.9
Huentota Valley	Potrerillos	AA-90282	$2181 \pm 47$	-260	-12
	Odisa	AA-90284	$529 \pm 42$	1406	-7.5
	Zanjón de los Ciruelos	AA-90280	$2068 \pm 46$	-89	-13.7
Badlands	Zanjón de los Ciruelos	AA-90279	$1536 \pm 45$	512	-9.1
	Campo Gorgoñi	AA-98704	$2025 \pm 36$	-27	-11.6
	Barrancas Yac. 2	AA-66560	$2084 \pm 40$	-107	-13.6
	Barrancas Yac. 1	AA-98705	$1597 \pm 38$	473	-5.7
	Finca Furlotti	AA-98706	$378 \pm 50$	1523	-8.8
Jaurúa Valley	Alto Verde	AA-66563	$1736 \pm 49$	301	-10
	Cápiz Alto	AA-101145	$246 \pm 44$	1658	-12.5
	Cápiz Alto	AA-101146	$423 \pm 41$	1467	-10.3
	San Carlos	AA-66562	$177 \pm 34$	1773	-10.2
	San Carlos	AA-66567	$142 \pm 41$	1807	-12.3
	Viluco	AA-6559	$208 \pm 38$	1769	-12.9



**Figure 1.** Location of the sub-regions and main sites of Mendoza and San Juan

*Figura 1. Ubicación de las subregiones y principales sitios de Mendoza y San Juan*

anean climate with cold winters, with ca. 50 days of frost and 106 mm of annual rainfall, and average temperatures of 18.3°C and 4.2°C for the warmest and coldest months, respectively (Servicio Meteorológico Nacional, 1958).

The northeastern lagoon sector (500-600 m a.s.l.) is furrowed by multiple paleochannels of the Mendoza River. It is an area with deep soils of fine texture (clays and silts) in a landscape characterized before the recent anthropic impact (last 500 years) by the presence of lagoons, carob forests, and sectors with

dunes. The climate is arid tropical with cold winters, with more than 40 days of frost and 83 mm of annual precipitation. The average temperatures of the warmest and coldest months are 25.4°C and 7.2°C.

The Huentota Valley or Depression of Mendoza-Tulumaya (750-800 m a.s.l.), is a low area located to the east of the southern precordilleran extreme, filled by the alluvial cones of the Mendoza River (Polanski, 1954). It has deep sandy to loamy soils. The climate is arid, attenuated tropical with cool winters, with ca. 50

days of frost per year (especially between May and August). The rainfall reaches 150 mm and the average temperatures of the warmest and coldest months are 23.1 °C and 6.7 °C.

The Jaurúa Valley occupies the Depression of the Huarpes. It spreads throughout the Yaucha Creek and the upper segment of the Tunuyán River. It is a space with deep, fertile loamy soils, located between 880 and 1100 m a.s.l. It has a semi-arid, warm tropical climate with very cold winters and more than a hundred days with frosts between April and October. The annual precipitation is 313 mm and the average temperatures for the warmest and the coldest months are 20.8 °C and 4.1 °C.

The badlands of Barrancas, located south of the Mendoza River between 700 and 780 m a.s.l., are made up of easily erodible, alluvial, and colluvial soils (Regairaz, 1979). The climate of the area is arid, attenuated tropical with cool winters and ca. 50 days with frosts a year. The annual rainfall is 150 mm, and the average temperature of the warmest and coldest months is 24.9 °C and 6.6 °C, respectively.

## RESULTS

Provincial trends of  $\delta^{13}\text{Cap}$  and  $\delta^{15}\text{N}$  show the absence of the post-1408 AD segment in San Juan. The average curve of  $\delta^{13}\text{Cap}$  tends to lower Mendoza's maize consumption and to raise that of San Juan for the period 300-750 AD. Nevertheless, the provincial curves do not display significant differences respecting the average (**Figure 2**). For the period 600 BC-800 AD,  $\delta^{15}\text{N}$  curves present more important differences between San Juan and Mendoza (**Figure 3**). Those

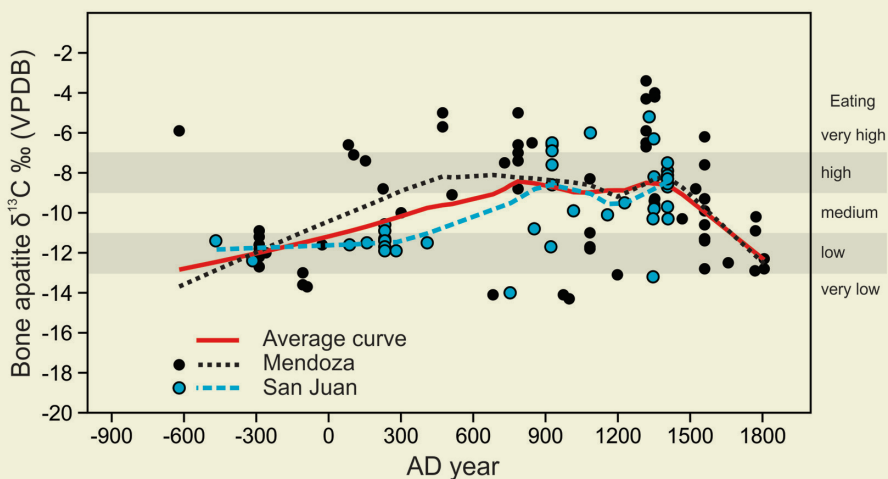
differences are greater when considering the zonal trends inside Mendoza, mainly regarding the Northwest, Northeast and Barrancas zones for  $\delta^{13}\text{Cap}$  (**Figure 4**), and the Northwest and Barrancas zones for  $\delta^{15}\text{N}$  (**Figure 5**).

Samples from the Northeast (682-1198 AD) and Jaurúa Valley (1467-1807 AD) show a significant temporal restriction, whereas Northwest and Barrancas present extensive periods lacking samples (**Figure 4**).

## DISCUSSION

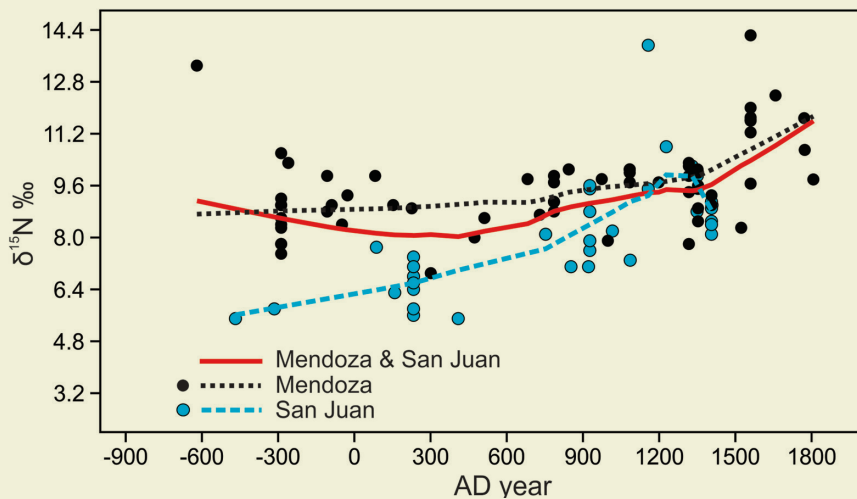
### Pre-Hispanic indigenous consumption

According to the regional trends proposed by Gil et al. (2014), from ca. 600 BC up to 800 AD there is a change from diets dominated by  $\text{C}_3$  resources to others in which maize ( $\text{C}_4$ ) contributes approximately 50% of consumption. These authors state that between 800 and 1450 AD the values oscillate around  $-8\text{‰}$ , which would reflect a mixed diet with a substantial contribution of  $\text{C}_4$  resources. As seen in **Figure 2**, although the tendency is the same, the average consumption of  $\text{C}_4$  plants in Mendoza seems to be just slightly negatively affected by the samples of San Juan and vice versa. The variations are greater at a local scale. Thus, the regional trend is not representative of the situation recognized in different sub-regions integrated into the regional reconstruction, except for Huentota Valley (**Figure 4**). This discrepancy appears for the period 600 BC-1300 AD in the Northwest, where values fluctuate between  $-6\text{‰}$  and  $-7\text{‰}$  (very high consumption), with a sharp fall towards 1050 AD. During this period, instead, the average curve points



**Figure 2.** Loess curves showing  $\delta^{13}\text{C}_{\text{ap}}$  chronographical trends for San Juan and Mendoza samples

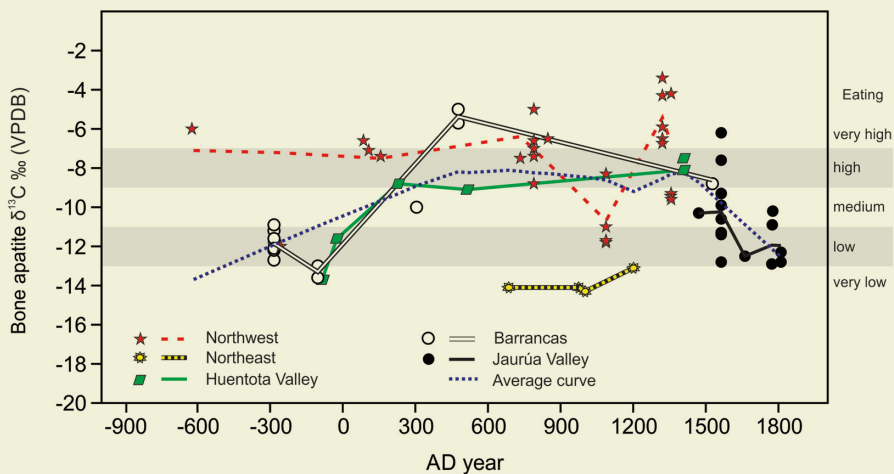
*Figura 2. Curvas Loess que muestran las tendencias cronológicas  $\delta^{13}\text{C}_{\text{ap}}$  para las muestras de Mendoza y San Juan*



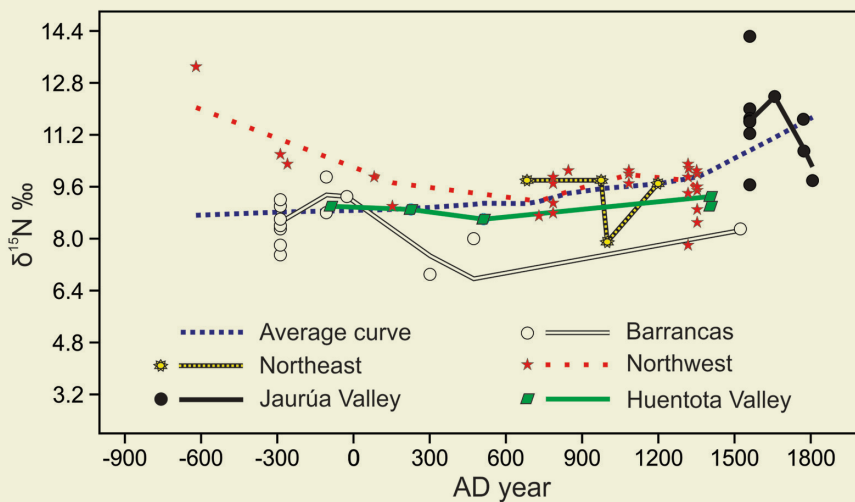
**Figure 3.** Loess curves showing  $\delta^{15}\text{N}$  chronographical trends for San Juan and Mendoza samples

*Figura 3. Curvas Loess que muestran las tendencias cronológicas  $\delta^{15}\text{N}$  para las muestras de Mendoza y San Juan*





**Figure 4.** Loess curves showing  $\delta^{13}\text{Cap}$  chronological trends for Mendoza sub-regions  
*Figura 4. Curvas Loess que muestran las tendencias cronológicas  $\delta^{13}\text{Cap}$  para las subregiones de Mendoza*



**Figure 5.** Loess curves showing  $\delta^{15}\text{N}$  chronological trends for Mendoza sub-regions  
*Figura 5. Curvas Loess que muestran las tendencias cronológicas  $\delta^{15}\text{N}$  para las subregiones de Mendoza*



a raise from very low to high consumption. It is important to point out that in the sites Jagüel II, Jagüel III, Agua de la Tinaja and Cueva El Jagüelito (all in this sub-region) have appeared the only archaeological evidence of cacti (Bárcena & Roig, 1982; Bárcena et al., 1985; Roig & Bárcena, 1983; Sacchero et al., 1989), CAM plants whose  $\delta^{13}\text{C}$  values partially overlap with those of  $\text{C}_4$  plants. However, regional values for cacti generally fall between  $-14\text{‰}$  and  $-11\text{‰}$  (Llano & Ughan, 2014), so their effect on the sub-regional curve (if any) must have been minimal, and in no way the cacti may be responsible for the  $\delta^{13}\text{Cap}$  values obtained. Other local  $\text{C}_4$  plants may have been part of the diet, but regrettably they do not appear in the archaeological record, and it is quite difficult to estimate the importance of their use.

Samples from Barrancas, with a curve range from  $-6\text{‰}$  to  $-8\text{‰}$  for the period ca. 300-1500 AD, also gave values that correspond to greater consumption of corn. The largest gap arises in the Northeast, where the consumption is very low to low ( $-14$  to  $-13\text{‰}$ ), in sharp contrast to the average curve. The documentary sources indicate that in this sub-region the natives dried and ground the roots of cattail (*totorá*) to make bread (Techo, 1897; Facultad de Filosofía y Letras, 1927; Lozano, 1755), and also ate roots of other plants (Ovalle, 1646). Some  $\text{C}_4$  plants (Llano, 2009) observed in the current local vegetation (e.g., *Sporobolus rigens* and *Atriplex lampa*) were possibly part of those resources. However, the high  $\delta^{13}\text{Cap}$  values recorded in this area do not allow us to maintain that these plants were an important part of the local diet.

With respect to measures of  $\delta^{15}\text{N}$ , the general curve shows a slight fall in values

towards 300 AD and then a constant increase that reaches  $12\text{‰}$  at the end of the XVIII century. However, curves separation corresponding to Mendoza and San Juan indicates important differences between both provinces (Figure 3), mainly the absence of that decrease in the former and its marked presence in the latter. Likewise, disaggregation by sub-regions shows some different situations (Figure 5). Thus, the curve corresponding to Barrancas shows an abrupt drop between 288 BC and 473 AD that coincides with a marked increment in the values of  $\delta^{13}\text{Cap}$ . These values could refer to a fall in meat consumption and an increase in maize eating, respectively. In the northwest area, there is a significant decrease in the values of  $\delta^{15}\text{N}$  between 620 BC and 730 AD, which could indicate a lower proportion of meat in the diet. Moreover, Huentota Valley sub-region shows an increase close to that shown by the regional curve, although without the abrupt rise registered after 1450 AD, only observed in the Jaurúa Valley sub-region between 1560 and 1807 AD.

Definitely, although the integration of partial situations for the reconstruction of a regional sequence can be a valuable general reference, in this case the result does not seem to be representative of the situations observed in most of the areas considered, evidencing the importance of analyzing the local context in each case, including the possibility of store the grain in silos.

### Maize consumption in the Inca and Colonial Periods

Only one of the analyzed samples corresponds to the Inca period. It is the one obtained in Finca Furlotti, dated 1523

AD. The  $\delta^{13}\text{Cap}$  value of this individual was  $-8.8\text{‰}$ , which would indicate an important presence of maize in the diet. In Mendoza, the chronologically closest individuals were dated in 1406 AD and show values of  $-7.5\text{‰}$  and  $-8.1\text{‰}$ , which also indicate a relatively high maize consumption. In San Juan, pre-hispanic samples chronologically closest are nine from Zonda Paredón (1406 AD), which present an average of  $-8.2\text{‰}$ , and one from Barrio Reina Mora (1408 AD), with a value of  $-10.3\text{‰}$  (Gil et al., 2014). Therefore, the available information does not indicate a lower consumption of maize during the Inca period.

The period related to the Spanish conquest started around 1551, the date of the first documented contact between Spaniards and local natives (Draghi Lucero, 1954). After this date, two concentrations of samples appear, one dated around 1560-1580 AD and another between 1777 and 1808 AD. The first one, corresponding to Cápiz Alto (in central Mendoza), presents a high internal variability within a group of individuals dated to 1560 AD, with  $\delta^{13}\text{Cap}$  values ranging from  $-6.2\text{‰}$  to  $-11.4\text{‰}$ , which would reflect important (high) to low contributions of maize in the diet, respectively. This situation does not show a drastic decline in maize consumption, which only seems to be observed in the second nucleus of samples, corresponding to five specimens from San Carlos dated to the end of the eighteenth and beginning of the nineteenth centuries. The drop is neither recorded in San Juan, where the curve ends up in about 1400 AD (10 individuals with values between  $-7.9\text{‰}$  and  $-10.3\text{‰}$ ; Gil et al., 2014).

This situation does not evidence a decline in the consumption of  $\text{C}_4$  resources

coinciding with local Inca domination (ca. 1480-1540 AD) and the subsequent Spanish conquest (1561 AD).

## Effects of climate on maize production

One of the most significant suggestions concerning the analyzed subject is that the environmental conditions of the LIA (1370-1750 AD) would have turned maize into a risky crop (Gil et al., 2014) and would have led to a decrease in its production and consumption. However, although the fall in temperatures starts since 1370 AD, the marked decrease in maize consumption is recorded only in individuals from the late eighteenth and early nineteenth century. Even since 1560, some individuals provide  $\delta^{13}\text{Cap}$  values of  $-6.2\text{‰}$  and  $-7.6\text{‰}$ , indicating an important role of  $\text{C}_4$  resources in the diet. The question then arises to whether the reduction in temperatures necessarily led to diminishing maize production in the region.

The subject cannot be solved from the Archaeology perspective due to the lack of data. The documentary information is very scarce, but in the middle of the XVII century a Jesuit chronicler pointed out that in Cuyo “the whole country is famous for nothing to much fruitfulness” and “produces such abundance of corn, wine, and other fruits, that it supplies the neighboring countries” (Techo, 1704). At the end of the eighteenth century another Jesuit affirmed the continuity of this situation for the nearby Chile (from where comes the paleoclimatic information of Laguna Aculeo): “maize grows extremely well in Chile, and the inhabitants cultivate eight or nine varieties of it, several of which are very pro-

ductive” (Molina, 1809). Given that these latter observations would coincide with an improvement in the environmental conditions after the LIA, and with the lower native utilization, these cases may not reflect the scale of maize production or the level of consumption by non-indigenous populations.

From the ecological point of view, there is no evidence of a decrease in the possibilities of maize cultivation during LIA. Maize, like other crops, is sensitive to both thermal variation and drought. In this species, the major effect of water stress is the delay in the formation of female flowers, increasing the anthesis-stigma formation interval (ASI) that seriously affects production. Furthermore, the cardinal temperatures are: lethal,  $-1.8/46^{\circ}\text{C}$ ; in anthesis,  $7.7/37.3^{\circ}\text{C}$ ; whole plant,  $6.2/42^{\circ}\text{C}$  (Sánchez et al., 2014). Maize dies at temperatures below freezing point. These values are far from those reconstructed at Laguna Aculeo (von Guten et al., 2009), which only show a decrease of  $1.02^{\circ}\text{C}$  (Gil et al., 2014) in average summer temperatures between the periods 1150-1369 and 1370-1750 AD.

The impact of the LIA may have been of little intensity in the extra-mountain environments of the area. According to Zárate (2002), LIA in this region, would not have been a continuous range of colder or wetter conditions, but a period marked by variability. Studies carried out in central Mendoza indicate that the Late Glacial Maximum did not significantly modify the vegetation cover of the low zones (Martínez Carretero et al., 2014), so its effects would have been restricted mainly to the higher mountainous sectors 2500 m a.s.l. During the LIA, in the Mendoza river basin (ca.  $33^{\circ}\text{S}$ ), glaciers

could descend in some ravines down to 2400 m a.s.l. (Mercer, 1976; Wayne and Corte, 1983; Stingl & Garleff, 1985; Espizúa, 1993), remaining mostly in the higher mountain ranges. A similar situation has been observed in central-southern Mendoza (ca.  $35^{\circ}\text{S}$ ), in the upper part of the Rio Grande basin (Espizúa & Pitte, 2009).

Therefore, the effects of the LIA in latitudes of central-west Argentina are expected to have similarly centered on the higher mountain range with little or no manifestation in the lower valleys (700-2000 m a.s.l.), where cultivation of corn was feasible.

Finally, there is no data to suggest that periods of significant late frost during the LIA affected maize production. In these situations, assimilates accumulated at high levels in maize stems remobilize towards grain production, involving the action of abscisic acid (stress hormone) from the root to the aerial part of the plant, and of other growth regulators (Jurgens et al., 1978; Ribaut et al., 2009).

The above information suggests that, in agreement with the scarce documentary data, in general, maize cultivation would not have decrease during LIA due to environmental causes.

### **Spanish conquest and its effects on the indigenous economy**

Beyond the occurrence of environmental changes, there is a cultural cause for explaining diet shifts in indigenous groups during Colonial times: the proven disruption and decomposition of local native societies. Although considered, this cause seems to have been underestimated against the explanatory potential of environmental factors (Gil et al., 2014).

The beginning of the decline in maize consumption coincides exactly (samples of Cápiz Alto dated to 1560 AD) with the start of the Spanish conquest of the Huarpe territory (1551-1561 AD). The use of the “Encomiendas” system began in the region around 1552 AD, a decade before the founding of the first cities. In a few decades, a large part of the local indigenous population was transferred to Chilean cities, with the consequent rupture of family ties and mechanisms of economic production (Prieto, 2000). Moreover, according to Michieli (1994, 1988), the process of transferring natives to Chile was so marked that by 1640 “the indigenous depopulation of the central valleys where Huarpe population was concentrated” would have occurred. Within this framework, also there were various movements of the local groups (Parisii, 2003) that gave rise to a totally different configuration of the occupation and exploitation of the territory. Prieto (2000) and Abraham & Prieto (1981) estimate that by the middle of the seventeenth century the number of Huarpe natives living in Mendoza would have been cut by half.

In addition, some sources point to a limitation in the production and consumption of maize in southern Chile, due not to environmental reasons but because of the Spanish conquest and the arduous struggle with the Araucanians. In fact, in the second half of the sixteenth century the Indians “did not want to sow for fear of supplying by chance some food to their enemies, and with such a patriotic purpose, they preferred to eat only wild chives, seeds and legumes” Correa Vergara (1938). According to González de Nájera (1889), who wrote in the 17th century, at the begin-

ning the Spanish conquest of Chile was based fundamentally on the corn taken from the natives. But then, for strategic reasons, the natives began to plant wheat and barley instead of corn, since these cereals required less care, gave them earlier harvests and did not require flat areas (easy to find by the Spaniards) for their cultivation.

As a result, both the time lag between the onset of the LIA and the decline in maize consumption by indigenous people, and the dramatic change in the economic and social conditions of local communities during the colonial period, suggest that in order to explain shifts in native diet, climate change could constitute a minor factor (if any) compared with the development of a generalized crisis of the indigenous world as a result of the Spanish conquest.

## CONCLUSIONS

The general  $\delta^{13}\text{C}_{\text{ap}}$  curve generated for San Juan and Mendoza shows important differences with the sub-regional situations of Mendoza. To a certain extent, these differences respond to the fact that the curve is not an average of zonal situations but an aggregation of samples of different periods in each sub-region. As a result, even when Mendoza's general curve is considered alone, it is not representative of what is recorded in sub-regions such as the Northwest or the Northeast of Mendoza (**Figures 2 and 4**), and the Colonial segment is only applicable to the sub-region where the samples originated (Jaurúa Valley), so in the other areas the situation could be different. Also, the consumption of maize during the Inca period cannot be characterized due to the scarcity of data, and

the only available sample indicates a significant presence of C<sub>4</sub> resources in the diet and not a marked decrease.

The available data do not allow us to establish the decline of the maize crop in the region during the colonial period, assumed as a reflection of a drop in indigenous consumption, or its causal relationship with adverse environmental conditions during the LIA. By contrast, the documentary data for the mid-seventeenth and late-eighteenth centuries reflect high levels of maize production, suggesting that the climatic variations recorded in the area did not have a significant impact on the cultivation of this cereal.

Finally, even when future work verifies the decline in the consumption of maize by the indigenous groups at regional levels, such variation in diet could be interpreted as one of the traumatic effects of the conquest on local societies, and it should not necessarily imply low maize production or low consumption in the non-indigenous sectors of the population.

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